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SMAW CERAMIC WELD BACKING EVALUATION

FINAL REPORT

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FOREWORD

The purpose of this report is to present the results of one of the research and development programs Which was initiated by the members of the Ship Production Cummittee of The society of Naval Architects and Marine Engineers and financed largely by government funds through a cost-sharing contract between the U.S. Maritime Ministration and Sun Ship, Inc. The effort of this project was directed to the development of improved methods and hardware applicable to shipyard welding in the U.S.. Shipyards.

Dr. Leslie W. Sandor and Mr. J. Fallick were program manager, Mr. T. E. Bahlow of Offshore power Systems (OPS) was Project Manager, and Mr. R. E. Cantrell, Mr. S. B. Hollwarth and Mr. D. J. St. Pierre of OPS were the Principal Investigators.

Special acknowledgement made the members of Welding Panel sp-7 of the SNAME Ship Production Committee who served as technical advisors in the preparation of inquiries and evaluation of subcontract proposals and to Offshore Power Systms' C. Soares, A. Boulet, R. Huffstetler, D. and D. Gionet, and to Newport News' B.C. Howser and M.I. Tanner for making possible the report compilation.

1.0 ABSTRACT

Representative ceramic weld backing systems were evaluated with Several SMAW process variations to determine their efficacy to produce volumetrically sound root beads and visually acceptable back bead weld contours not requiring subsequent backside welding or repair. Ceramic tile backing was found to bring the use of open root, low hydrogen SMAW within the realm of practicality. Operator training and/or retraining was found to be especially critical. Special technique considerations were necessary to assure soundness in restart areas. Chevron porsity and piping was much less frequent than in FCAW. Ceramic tile backing was additionally found promising with cellostic type (i. e., E601O) electrodes. Promising joint designs, parameters and techniques were identified for SMAW over ceramic backing.

2.0 INTRODUCTION (PURPOSE OF WORK)

In the shipbuilding industry, three exists, for a varity of reasons (expossd areas, non-repetitive jobs, inaccesibile areas, etc.), a demand for the use of SMAW for full-penetration butt welds without a permanent backing strip. While back grinding and/or back welding may be possible in sane of these areas, in many it is not. Full penetration, one-side (open root) welding offers manyeconomic advantages provided consistant, repeatable back side contours and weldment soundness is obtainable. The inherent difficulty with full penetration, one-side welding is support of the liquid weld metal against the force of the arc and gravity. This may be accomplished by capillarity or by capillarity and inherent puddle support.

Open root, one-side welds with SMAW are, in certain commercial applications, made with low slagging, cellulose type electrodes (e.g. E6010). These electrodes have a mostly cellulose (hydrocarbon) covering frequently made from wood flour. The covering produces gaseous products (CO, CO_2, H_2O and hydrogen) upon decomposition which shield the weld puddle and are then carried away by the atmosphere. Dependence on a gaseous rather than a liquid shielding medium results in very little thermal insulation and a rapidly freezing, relatively small puddle. The puddle insufficiently small that support in open root welding is accomplished primarily by capilarity alone. The low slag level also increases operator visability and reduces the probability of inclusions. However, the hydrogen produced by coating decomposition of cellulose type electrodes is undesirable when welding the higher strength low alloy steels common to ship construction. Low hydrogen electrodes are advantageous when welding these low alloy steels with SMAW.

Low hydrogen electrodes depend on a blanketing liquid slag as their shielding medium. The significant thermal insulation, as a result, promotes a slowly freezing, relatively large puddle. Iron powder additions in sane low hydrogen electrode coatings further add to the puddle size. Due to a greater ratio of liquid weight to surface tension, the larger puddle becomes more difficult to support by capillarity alone. In open root, one-side applications, as the size of a puddle supported by capillarity increases, the puddle may succumb to the arc force or gravity and the possibility of burn-through and/or slag inclusions is greatly increased. Open root one-side welding with low hydrogen electrodes is a difficult, quite inconsistent proess.

When some type of puddle support is added, the weight of the heavier, more fluid puddle is supported, preventing or decreasing undesirable bead shapes due to uncontrolled flow of the large puddle. The supported puddle is less susceptible to joint irregularities than the puddle supported only by the edges of the joint (capillarity) and on the "ragged edge" of falling away. Also since there are fewer irregularities in a supported puddle, there is less chance of entrapped slag even with a greater slag volume. By decreasing the chance of slag entrapment and undesirable puddle flow, the criticality of puddle visability is decreased. In open-root, low-hydrogen welding, decreased visability of the puddle due to extra slag prevents the operator frmo anticipating the occurrence of these events (slag flow, puddle breakdown, etc.) and possibly manipulation his electrode to avoid them. With the addition of some type of puddle support the criticality of joint fitup would/should be decreased.

Many one-side welding situations, however, preclude the utilization of a steel backing. Them remaining choice when puddle support and capillarity is required (such as is usually the case with low hydrogen electrodes) is a single-welded joint made practical by a nonfusible means of puddle support, such as ceramic tile backing

Ceramic tile backing, in conjunction with shielded metal arc welding, continues to increase in usage due to the previously mentioned ceramic advantages. A previous state-of-the-art evaluation (Ref. 1,) determined the efficacy of ceramic tile backing with flux cored arc welding (FCAW) and submerged arc welding (SAW. The objectives of this project are to evaluate:

The efficacy of ceramic tile backing in Shielded Metal Arc Welding (SMAW) applications relative to producing visually acceptable and volumetrically sound one=side butt weldments requiring on cosmetic grinding and/or welding repair.

The efficacy of "hot-start" techniques when employed in SMAW over ceramic backing.

3.0 EVALUATION PLAN

Offshore Power Systems performed an evaluation of techniques and parameters for shielded metal arc welding (SMAW) over ceramic tile backing. The evaluation utilized popular low hydrogen electrodes from several vendors (Airco, McKay, Atom Arc, and Varios [not the low slagging coating]) of the E7016 and E7018 specifications. Electrodes of the E6010 specification were used for comparison with the low hydrogen electrodes. The evaluation consisted of a basic array of test assemblies and some additional investigation of bead junction techniques with E7018 electrode. The electrodes were used in 1/8" and 5/32" diameter sizes over three ceramic types (Kuder, 1CR-062; Varios, VLG-02; and 3-M, SJ-8069).

3.1 Basic Array Of Testing

All welding was performed with direct current reverse polarity (DCRP). Welding was evaluated in the flat (1G), horizontal (2G), and vertical (3G) positions for each electrode, size and ceramic combination. The specific combinations of electrode type and size, welding position, and ceramic type constituting the basic array of test assemblies are identified in Table 3.1. In Table 3.1 each test is assigned a numeric-alpha-numeric identifier. The identification scheme is as follows:

```
N(N) - A - N
 |     |   |
 |_____|___|______ A numeric character(s) denoting electrode
       |   |       type & size
       |___|______ An alpha character denoting ceramic type
           |
           |______ A numeric character denoting welding position
```

All tests consisted of run-on/run-off tab butt welding of two 1/2 inch thick A36 plates approximately 8" long. A 37 1/2° bevel (75° included angle) was used throughout. The various root opening and root face dimensions employed are indicated in Table 4.1.

Each formal test combination identified in Table 3.1, except those for which similarity with other tests deemed it innecessary, was preceeded by a number of "practice" test assemblies to determine parameters, techniques and joint configurations. These practice test assemblies are identified with the suffix "P" and a sequential number. When the appropriate parameters and techniques were satisfactorily identified, a test assembly was welded, visually inspected for soundness and back bead contour, radiographer for soundness, and a guided not bend specimen tested to the requirements of ASME Section IX. Radiography was performed and evaluated to the requirements of both NAVSHIPS 0900-003-9000 and American Bureau of Ships (ABS) "Hull Radiography".

A DC not start system was devised utilizing a conventional Hobart Cyber-Tig power supply. The unit was adjusted to provide the desired hot start current with the foot pedal fully depressed. A "stop" was placed under the foot pedal heel and adjusted to provide the desired normal welding current when the pedal was released rather than breaking the circuit as normally occurs. A schematic of this arrangement appears in Figure 3.1. Although the arrangement provided the operator with a continuous current range from "muual" to "hot start", the operator was instructed to use only the extremes, i.e. fully depressed or released.

3.2 Welding Technique & Evaluation Methods

Welding technique over ceramic backing bore a marked similarity to the open root technique in that the "keyhole" technique, commnly used to maxmize penetration with SMAW open root welding, was also used with ceramic backing. With this technique, the heat of the puddle melts the root faces of the joint just ahead of the puddle. The melted base metal volume ahead of the puddle then flows by capilarity back into the puddle leaving an open cresent or "keyhole" ahead of the puddle. The welder maintains the keyhole by maintaining a short arc length (low voltage, narrower bead and "stiffer" arc for better penetration) and by holding travel speed slow enogh to provide time for the base metal to melt and flow. Travel speed conversely must be fast enough to prevent flow ahead of the puddle. The thickness of the rout face is also significant in that excessive root face thickness does not permit adequate base metal melt ahead of the puddle.

Throughout the evaluation, welding was performed with a slight lead angle to direct the arc onto the puddle and to keep most of the molten electrode slag "washed" to the rear of the puddle prior to solidification. This lead angle was approximately 20° for horizontal (2G) position, 15° for flat (lG) position and 0-30° for vertical (3G) position. For horizontal (2G) position there was also a slight work angle (electrode above a horizontal plane through the arc)of about 20°. Since the ground was on the lower plate, the arc tended toward the lower plate following the more direct path to ground. This aggravated "fingernailing" with the Varies electrode in the horizontal position since the "bottom” coating melted off more rapidly than the top leaving an obstructing projection at the top. There was no work angle (the electrode was 90° to plate on either side) for flat and vertical positions. For restarts in the vertical position the lead angle was increased to 30° or more to heat up the restart area.

During the course of evaluation, a per plate average of two restarts for flat position welding, three restarts for vertical and one restart for horizontal was employed.

The technique initially used for terminating the arc with low hydrogen electrodes was to turn and run slightly up the bevel face then quickly "snap" the arc. For E6010 electrodes the arc was terminated by increasing the lead angle slightly (directing the arc more back toward the puddle) then quickly "snapping" the arc while still in the keyhole. Although these techniques provided a tapered crater to better facilitate restarting, they were found to be somewhat prone to promating occasional crater cracking. Later evaluation suggested that conventional crater filling techniques be employed in production applications to minimize the cracking phenomenon.

Starting over ceramic backing in the flat (lG) position, the arc was initiated with normal. Welding current on the run-off tab approximately 1/4″ from the actual root opening then moved toward the root opening. At the root opening, hot start current was used to melt into the sides of the bevel and penetrate into the root opening to form a keyhole. Once the keyhole was established, normal welding current was resumed. The initial starting technique for ceramic backing in the horizontal (2G) position was the same as lG, except once a keyhole was established, the bottom plate was favored to prevent undercutting at the top of back bead (back bead sag).

When restarting over ceramic backing in the flat (lG) position, the existing crater area was de-slagged and when necessary, rapered back approximately 1/4" from the keyhole by grindng. This enabled the hot start to melt through the existing crater area more easily and reduced chances of slag inclusions. The arc was started at the rear of the taper. Using hot start to melt through the taper, welding proceeded to the keyhole. Once in the keyhole, the electrode was positioned in front of the puddle but not out of keyhole. Welding then proceeded without hot start. For restarting in the vertical (3G) position, the arc was started at the crater’s edge with hot start on. The slag was melted out and the keyhole reestablished using about a 25° lead angle.

The "practice" and "formal" test assemblies afforded ample opportunity to judge operator appeal and the effects of parameters and techniques on back bead contour. The "formal" test assemblies permitted weldment soundness evaluation via radiographic and root bend examination. Root bending additionally provided a measure of weldment ductility.

Both adhensive (Kuder and 3-M) and magnetic (Varios) devices were used to position the ceramic tiles under the weld joint. A previous report on FCAW and SAW over ceramic backing (Ref. 1) discusses the effectiveness of the various ceramic attaching methods. No differences were noted with SMAW.

This evaluation did not include the low-slagging Varies electrode intended by the manufacturer for use with their ceramic backing. The electrode was unavailable domestically. A quantity, braver, of Varies 1/8" diameter E7016 (BL-100) and E7018 (BL) was evaluated although not of the special mating formulation intended for ceramic backing applications. The supply of Varies electrodes used were less than satisfactory for evaluation purposes since they were received without the customary hermetic seal moisture protection provided for low hydrogen electrodes. The Varios E7016 and E7018 electrodes appeared dry when received, and were placed in a holding oven immdiately and were maintained at 250°F for the duration of the evaluation program.

Since the Varies electrodes received were not the type with coatings formulated for use over ceramic backing and since the Varios ceramic backing is maketed as a system utilizing this special electrode coating formulation and a "hot start" technique together with their ceramic backing, a fair evaluation of the foreign (Varios) ceramic/ electrode combination was not possible.

3.3 Further Investigation

Some special stop and restart testing was performed in which pairs of plates about 24" long were welded for short lengths with a root pass only. The root passes were sectioned longitudinally after back bead photographs were made and longitudinal macrophotographs taken of a start, a stop, a start on stop, a start on start, a stop on start and a stop on stop. All of this special testing was performed in the flat position with 5/32" diameter E7018 electrodes employing both hot and cold restarting.

TABLE 3.1

TEST COUPON IDENTIFICATION

ELECTRODE			KUDER CERAMIC (1CR+062)			VARIOS CERAMIC (VIG-02)			3-M CERAMIC (SJ8069)		
FOREIGN/ DOMESTIC	CLASS	SIZE	lG	2G	3G	lG	2G	3G	lG	2G	3G
FOREIGN	E7016	1/8	1K1	1K2	1K3	1V1	1V2	1V3	1M1	lM2	IM3
DOMESTIC	E7016	1/8	3K1	3K2	3K3	3V1	3V2	3V3	3M1	3M2	3M3
	E7016	5/32	4K1	4K2	4K3	4V1	4V2	4V3	4M1	4M2	4M3
FOREIGN	E7018	l/8	5K1	5K2	5K3	5V1	5V2	5V3	5M1	5M2	5M3
DOMESTIC	E7018	1/8	7K1	7K2	7K3	7V1	7V2	7V3	7M1	7M2	7M3
	E7018	5/32	8K1	8K2	8K3	8V1	8V2	8V3	8M1	8M2	8M3
DOMESTIC	E6010	l/8	10K1	10K2	10K3	10V1	10V2	10V3	10M1	10M2	10M3

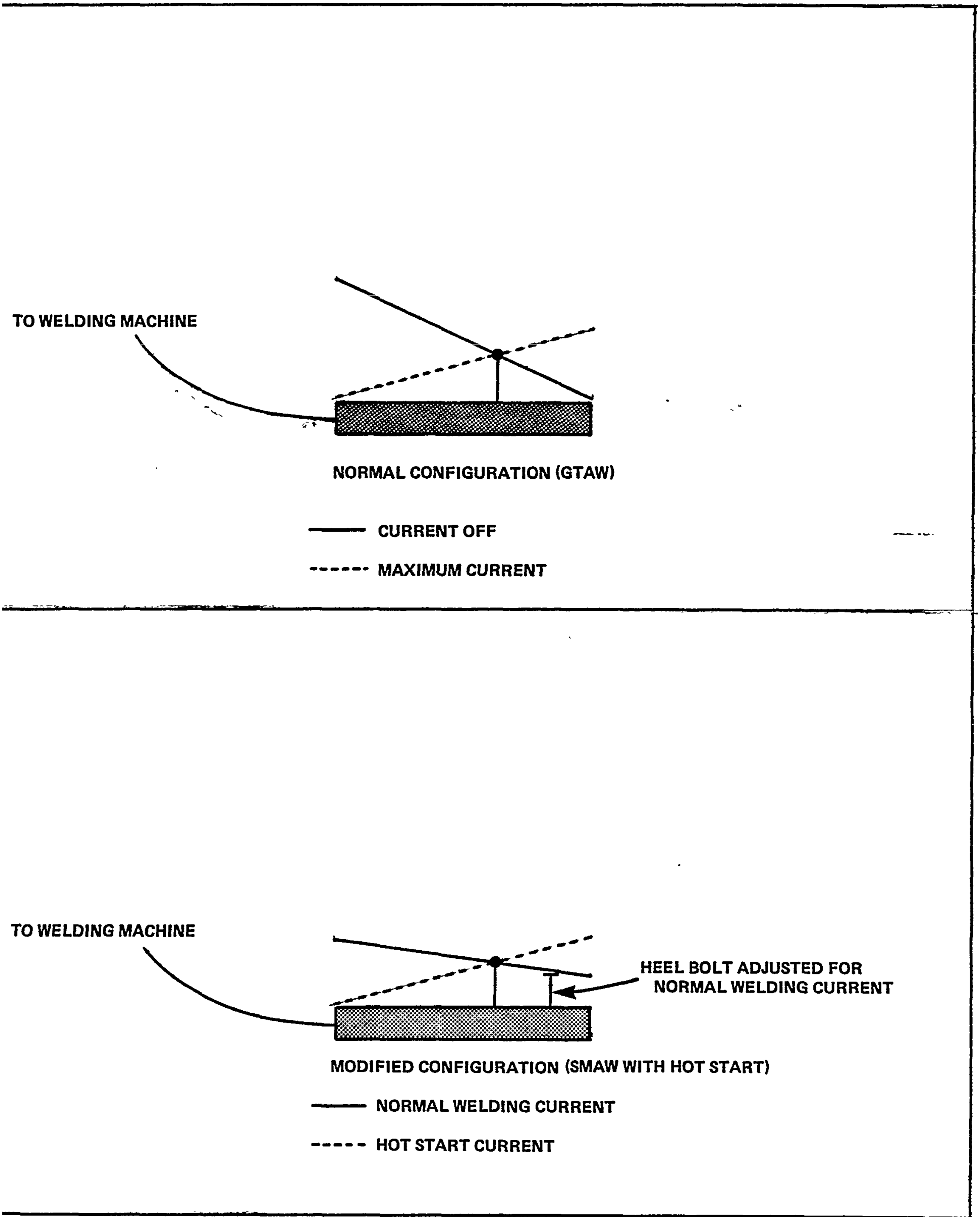


FIGURE 3.1
FOOT PEDAL MODIFICATION TO ACHIEVE HOT START

4.0 RESULTS

Table 4.1 identifies the welding data and NDE and mechanical testing results applicable to all test assemblies. Figure 4.1, "Representative Back Read Configurations and Cress-Sectional Macrophotographs", provides a representative sampling of back bead contours and weld cross sections actually encountered. Figure 4.28 "Longitudinal Macrophotographs of Stop and Restart Areas", provides information for certain stopping and restart methods used with ceramic tile backing. The information accumulated in the evaluatiom program and exhibited in Table 4.1 and Figures 4.1 and 4.2 permitted evaluation of SMAW in conjunction with ceramic tile backing with regard to:

- Weld soundness in both run and junction areas
- Back bead contours in both run and junction areas

Weldment toughness, ceramic attaching methods and ceramic neutrality as specifically relatd to FCAW and SAW processes were investigated and summarized in an earlier report (Ref. 1) in which no significant problems were identified. These areas were therefore not specifically investigated in this evaluation. Although the mailer SMAW puddle relative to an FCAW or SAW puddle may promote cooling rate differentials and resultant variations in toghness, weld metal toughness for the half inch thick low carbon steel used in this this and the earlier evaluation should not vary significantly. Toughness evaluations for thicker sections and/or higher strength steels may however warrant consideration.

As previously mentioned, stoping teechniques which did not fill the crater area resulted in sporadic centerline crater cracking. Such techniques, based upon data from this evaluation could promote problems in production applications and should be employed with caution.

TABLE 4.1
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning   [C] Center   [E] End

	JOINT		CURRENT/VOLT			ELECTRODE	REINFORCEMENT		BACK BEAD		ROOT BEND	RADIOGRAPHY	
TEST NO.	R.O.	R.F.	ROOT	H.S.	BAL.	MFG./ DESIG.	HEIGHT	WIDTH	TOE	RESTART	PASS/FAIL	ACCEPT REJECT	REMARKS
1K1	3/32	1/16	100 24	145 28	105 24	VARIOS/ BH-100	3/32	9/32	GOOD	GOOD	P	A	SURFACE ROUGH
1V1	7/64	1/16	95 22	140 28	110 24	VARIOS/ BH-100	1/16-1/32	5/16-1/8 (INCONSIS.)	GOOD FUSION BUT INCON-SISTENT	GOOD	P	A	——
1M1	3/32	3/32	95 22	125 28	105 24	VARIOS/ BH-100	1/8 NOT UNIFORM	3/8	GOOD	GOOD	NO TEST (SLIPPED)	A	SLAG NEAR [B]
3M1-P1	3/32	1/16	110	185	-	AIRCO	INSUFFICIENT PENETRATION.						
3M1-P2	7/64	3/32	110	185	-	AIRCO	GOOD PENETRATION WITH ONE POROSITY DEFECT AT THE START. BEAD SURFACE GOOD.						
3M1-P3	7/64	3/32	110	185	-	AIRCO	PENETRATION GOOD WITH CHEVRON POROSITY IN VARIOUS LOCATIONS.						
3M1-P4	3/32	3/32	107	180	-	AIRCO	NO PROBLEMS.						
3K1	7/64	1/16	100 NR	160 NR	115 19		3/32 VISABLE CHEVRON EACH END	5/16-3/8	GOOD	GOOD	P	A	CHEVRON ~1 1/2" AT [B] CONFINED TO CRATER AT [E]
3V1	3/32	1/16	110 22	170 26	110 22		1/8	5/16	GOOD	GOOD	P	A	——

TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning   [C] Center   [E] End

	JOINT		CURRENT/VOLT			ELECTRODE	REINFORCEMENT		BACK BEAD		ROOT BEND	RADIOGRAPHY	
TEST NO.	R.O.	R.F.	ROOT	H.S.	BAL.	MFG./ DESIG.	HEIGHT	WIDTH	TOE	RESTART	PASS/FAIL	ACCEPT/ REJECT	REMARKS
3M1	1/8	3/32	110 22	185 27	115 23	ATOM ARC	1/32	5/16	GOOD VERY UNIFORM	SLIGHT CONCAVITY	P	A	——
4K1	7/64	1/16	125 20	220 24	145 22		1/16-1/8	3/8	≈1 1/2" OF SHARP RE-ENTRY	ROUGH-POOR PENETRATION	P	A	UNDERCUT POR. - [C]
4V1	1/8	1/16	130 24	230 28	145 23		3/32	1/8-3/8 BEAD WIDTH UNIFORM	GOOD	POOR	P	A	——
4M1	3/32	3/32	135 20	210 25	135 20	ATOM ARC	1/8	3/8	GOOD	GOOD	P	A	——
5M1-P1	3/32	1/16	105	170	-	VARIOS/ BH	LARGE KEYHOLE.						
5M1-P2	3/32	3/32	97	165	-	VARIOS/ BH	FAIR RESTART; ROUGH BEAD SURFACE.						
5M1-P3	3/32	3/32	95	160	-	VARIOS/ BH	UNEVEN PENETRATION FOR ABOUT 2".						
5M1-P4	3/32	3/32	95	160	-	VARIOS/ BH	"FINGERNAILING" A PROBLEM, ALSO ABOUT 2" OF INADEQUATE PENETRATION. (SEE NOTE 1)						
5M1-P5	3/32	3/32	100	170	-	VARIOS/ BH	PENETRATION NOT BAD.						

TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning [C] Center [E] End

	JOINT		CURRENT/VOLT			ELECTRODE	REINFORCEMENT		BACK BEAD		ROOT BEND	RADIOGRAPHY	
TEST NO.	R.O.	R.F.	ROOT	H.S.	BAL.	MFG./ DESIG.	HEIGHT	WIDTH	TOE	RESTART	PASS/FAIL	ACCEPT REJECT	REMARKS
5K1	3/32	3/32	105 24	135 34	105 24	VARIOS/ BH	1/8	1/4	GOOD	GOOD SLIGHTLY LOW	P	A	PIPE POR. NR. [B] OUT OF AREA OF INT.
5V1	3/32	1/16	105 22	145 28	105 22	VARIOS/ BH	1/8	1/4	INCONSISTENT BUT TIED IN	GOOD BUT LOW	P	R/B-C A/C-E	L.F. NR. [B] POR. NR. [E]
5M1	3/32	3/32	105 22	140 28	105 24	VARIOS/ BH	1/8-3/32	3/8	IRREGULAR BUT GOOD FUSION LINE	GOOD	P	A	—
7M1-P1	3/32	3/32	105	170	-	AIRCO/ CODE-ARC	STARTED OUT WITH HOT START (170A). RAN OFF TAB INTO GROOVE. DROPPED TO 115A WHICH WAS TOO HOT. CHANGED TO 105A FOR RUN. HAD AN EXCELLENT BACK BEAD UNTIL A NARROW BACK BEAD AREA OF 1/4" LENGTH AT A RESTART. ONCE NORMAL WELDING CURRENT (105A) WAS ESTABLISHED, BACK BEAD RETURNED TO A GOOD APPEARANCE. A SECOND START IN WHICH THERE WAS A LONGER HOLD TIME IN THE CRATER AREA APPEARED MUCH BETTER.						
7M1-P2	3/32	3/32	105	165	-	AIRCO/ CODE-ARC	WELDING RUN CHARACTERISTICC WERE SIMILAR TO PLATE # 7M1-P1. HAD PROBLEMS WITH THE LAST 5" OF RUN WHERE THE ROOT OPENING CLOSED TO ~1/16" IN WIDTH. THE FIRST 3" OF THIS WELD WAS VERY GOOD IN APPEARANCE AND TIE-IN.						
7M1-P3	3/32	3/32	105	165	-	AIRCO/ CODE-ARC	FULL PENETRATION BUT INCONSISTENT.						
7M1-P4	3/32	3/32	110	165	-	AIRCO/ CODE-ARC	INSUFFICIENT PENETRATION.						
7K1	3/32	1/16	105 20	165 22	110 20	AIRCO/ CODE-ARC	3/32-1/8	3/8	GOOD SLIGHT IRREGULARITY IN WIDTH	GOOD	P	A	—

TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning [C] Center [E] End

TEST NO.	JOINT R.O.	JOINT R.F.	CURRENT/VOLT ROOT	CURRENT/VOLT H.S.	CURRENT/VOLT BAL.	ELECTRODE MFG./ DESIG.	REINFORCEMENT HEIGHT	REINFORCEMENT WIDTH	BACK BEAD TOE	BACK BEAD RESTART	ROOT BEND PASS/FAIL	RADIOGRAPHY ACCEPT/REJECT	RADIOGRAPHY REMARKS
7V1	3/32	1/16	105 22	160 28	105 22	AIRCO/ CODE-ARC	1/16-3/32	7/16	GOOD	GOOD	P	A	——
7M1	3/32	1/16	105 20	210 28	110 22	AIRCO/ CODE-ARC	3/32-1/8	3/8	GOOD VERY SMOOTH AND UNIFORM	GOOD	P	A	POR. NR. [E] (1" @ VERY END)
8M1-P1	3/32	1/16	122	180	–	ATOM ARC	EXCELLENT RUN. GOOD PENETRATION.						
8M1-P2	3/32	1/16	130	210	–	AIRCO/ CODE-ARC	INCOMPLETE FUSION.						
8M1-P3	3/32	1/16	147	230	–	AIRCO/ CODE-ARC	INCOMPLETE FUSION BUT BETTER THAN 8M1-P2.						
8M1-P4	1/8	3/32	130	210	–	AIRCO/ CODE-ARC	EXCESSIVE PENETRATION.						
8M1-P5	3/32	0	130	210	–	AIRCO/ CODE-ARC	BLOW-THRU.						
8M1-P6	7/64	1/16	120	210	–	AIRCO/ CODE-ARC	PENETRATION EXCELLENT.						
8K1	3/32	1/16	122 22	180 24	130 22	AIRCO/ CODE-ARC	1/8	1/4-7/16	SHARP RE- ENTRY IN SOME AREAS	GOOD IRR. IN WIDTH	P	A	——

TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning [C] Center [E] End

	JOINT		CURRENT/VOLT			ELECTRODE	REINFORCEMENT		BACK BEAD		ROOT BEND	RADIOGRAPHY	
TEST NO.	R.O.	R.F.	ROOT	H.S.	BAL.	MFG./ DESIG.	HEIGHT	WIDTH	TOE	RESTART	PASS/FAIL	ACCEPT REJECT	REMARKS
8V1	3/32	1/16	120 24	185 26	145 24	AIRCO/ CODE-ARC	1/16	3/8-7/16	GOOD	GOOD	P	A	—
8M1	1/8	3/32	120 22	210 28	145 24	AIRCO/ CODE-ARC	1/16-3/32	3/16	GOOD	SLIGHTLY SHALLOW	P	A	POROSITY AT [C]
10K1	1/16	3/32	120 24	160 28	100 22	AIRCO	1/16	7/16	GOOD	SLIGHTLY CONVEX	F POROSITY	A	PIPE POR. NR. [E] OUT OF AREA OF INTEREST
10V1	3/32	1/16	100 24	140 28	110 26	AIRCO	1/32	1/4	GOOD	GOOD	P	A	PIPE POR. NR. [E] OUT OF AREA OF INTEREST
10M1	3/32	1/16	100 24	140 27	95 22	AIRCO	1/8	3/8	GOOD.	GOOD	P	A	—
1K2	3/32	1/16	105 24	125 27	N.A. N.A.	VARIOS BH-100	<——— "FINGERNAILING" PREVENTED SATISFACTORY COMPLETION. ———> (SEE NOTE 1)						
1V2	3/32	1/16	100 22	154 28	N.A. N.A.	VARIOS BH-100	<——— "FINGERNAILING" PREVENTED SATISFACTORY COMPLETION. ———> (SEE NOTE 1)						
1M2	<——— NOT WELDED DUE TO PROBLEMS WITH 1K2 AND 1V2 ———> (SEE NOTE 1)												
3M2-P1	3/32	3/32	100	165	-	AIRCO	PENETRATION EXCELLENT. RESTART EXCELLENT.						
3K2	3/32	3/32	100 19	160 22	110 20	AIRCO	1/32-1/16	1/4	GOOD	GOOD	P	A	SM. POR. NR. [C]

TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning [C] Center [E] End

	JOINT		CURRENT/VOLT			ELECTRODE	REINFORCEMENT		BACK BEAD		ROOT BEND	RADIOGRAPHY	
TEST NO.	R.O.	R.F.	ROOT	H.S.	BAL.	MFG./ DESIG.	HEIGHT	WIDTH	TOE	RESTART	PASS/FAIL	ACCEPT REJECT	REMARKS
3V2	3/32	1/16	100 20	150 26	105 22	AIRCO	1/16	1/4	GOOD	GOOD	P	A	——
3M2	3/32	3/32	110 20	170 27	110 20	ATOM ARC	3/32	5/16	VERY UNIFORM	FAIR WITH SLIGHT CRATER	P	R/B-C A/C-E	CHEVRONS & L.F. [B] - [C]
4M2-P1	3/32	3/32	160	240	-	AIRCO	PENETRATION GOOD. BEAD APPEARANCE GOOD. HAD CHEVRON POROSITY AT THE ENDS.						
4M2-P2	3/32	3/32	157	230	-	AIRCO	SOME CHEVRON POROSITY AT START. INSUFFICIENT TIE-IN.						
4M2-P3	3/32	3/32	157	230	-	AIRCO	SOME CHEVRON POROSITY.						
4M2-P4	3/32	3/32	157	230	-	AIRCO	CHEVRON POROSITY AT START OF RUN. PENETRATION SLIGHTLY EXCESSIVE AT END OF RUN						
4M2-P5	1/8	3/32	105	165	-	AIRCO	ONE RESTART IN THREE FAILED TO TIE IN PROPERLY. SOMEWHAT EXCESSIVE PENETRATION ~2" IN CENTER.						
4M2-P6	1/8	3/32	105	165	-	AIRCO	SOME IRREGULARITY IN BEAD WIDTH. ALL RESTARTS GOOD. PENETRATION SLIGHTLY EXCESSIVE.						
4M2-P7	1/8	3/32	105	165	-	AIRCO	EXCESSIVE PENETRATION.						
4M2-P8	3/32	1/16	105	165	-	AIRCO	EXCELLENT PARAMETERS. RESTARTS WERE HARDLY NOTICEABLE. EXCELLENT PENETRATION.						
4M2-P9	7/64	3/32	135	190	-	AIRCO	PENETRATION GOOD FOR FIRST 4".						
4M2-P10	3/32	3/32	135	190	-	AIRCO	GOOD WELD THROUGHOUT.						

TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning [C] Center [E] End

	JOINT		CURRENT/VOLT			ELECTRODE	REINFORCEMENT		BACK BEAD		ROOT BEND	RADIOGRAPHY	
TEST NO.	R.O.	R.F.	ROOT	H.S.	BAL.	MFG./ DESIG.	HEIGHT	WIDTH	TOE	RESTART	PASS/FAIL	ACCEPT/ REJECT	REMARKS
4K2	7/64	3/32	130 22	200 N.R.	145 24		1/16	1/4	GOOD MINOR CHEVRONS AT BOTH ENDS	GOOD	F (WORM-HOLE POROSITY)	R	CHEVRONS (INTER. OVER LENGTH)
4V2	1/8	3/32	135 24	210 28	140 23		1/16	5/16	GOOD VERY SMOOTH	GOOD	P	A	—
4M2	1/8	3/32	130 22	200 26	135 22	ATOM ARC	3/32	1/4	GOOD	GOOD	P	A	—
5M2-P1	3/32	1/16	105	170	-	VARIOS/ BH	"FINGERNAILING" WAS VERY PREVALENT.				(SEE NOTE 1)		
5K2	3/32	1/16	105 24	- -	- -	VARIOS/ BH	← "FINGERNAILING" PREVENTED SATISFACTORY COMPLETION. → (SEE NOTE 1)						
5V2	3/32	3/32	- -	- -	- -	VARIOS/ BH	← "FINGERNAILING" PREVENTED SATISFACTORY COMPLETION. → (SEE NOTE 1)						
5M2	3/32	1/16	105 22	-	-	VARIOS/ BH	← "FINGERNAILING" PREVENTED SATISFACTORY COMPLETION. → (SEE NOTE 1)						
7M2-P1	3/32	3/32	105	170	-	ATOM ARC	THESE PARAMETERS RESULTED IN AN EXCELLENT WELD.						
7K2-P2	7/64	1/16	120	200	-	ATOM ARC	PENETRATION GOOD. RESTART GOOD.						
7M2-P3	3/32	3/32	100	165	-	ATOM ARC	PENETRATION GOOD. RESTART GOOD.						

TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning [C] Center [E] End

	JOINT		CURRENT/VOLT			ELECTRODE	REINFORCEMENT		BACK BEAD		ROOT BEND	RADIOGRAPHY	
TEST NO.	R.O.	R.F.	ROOT	H.S.	BAL.	MFG./ DESIG.	HEIGHT	WIDTH	TOE	RESTART	PASS/FAIL	ACCEPT REJECT	REMARKS
7K2	3/32	3/32	120 20	180 24	120 20		1/16-3/32	5/16-3/8	GOOD	GOOD	F. GROSS CHEVRON, P - RETEST	R	CHEVRONS (INTER.-WORST AT [E])
7V2	3/32	1/16	110 20	170 28	115 22		1/32	5/16	GOOD VERY SMOOTH, UNIFORM BACK BEAD.	GOOD	P	A	----
7M2	3/32	1/16	105 20	170 26	110 22		1/32-1/16	5/16	GOOD	GOOD	P	A	POROSITY AT [E] AND NEAR [B]
8M2-P1	3/32	3/32	135	200	-	ATOM ARC	INCONSISTENT PENETRATION.						
8M2-P2	7/64	3/32	135	200	-	ATOM ARC	INCOMPLETE PENETRATION AFTER FIRST 3".						
8M2-P3	7/64	1/16	145	220	-	ATOM ARC	NO PROBLEMS.						
8K2	3/32	3/32	130 21	220 23	150 22		1/16	5/16	GOOD VERY UNIFORM	GOOD	P	A	----
8V2	3/32	3/32	90 20	210 26	145 23		1/32	1/4	SLIGHTLY LOW AT TOP -DUE TO SAG	ACCEPTABLE	P	A	MINOR POROSITY AT [B]
8M2	3/32	3/32	135 23	210 28	145 24		1/16	1/16	GOOD	GOOD	P	A	POROSITY AT [C]
10K2	1/16	1/16	90 20	145 24	100 22	AIRCO	1/16-3/32	3/8	GOOD	GOOD	P	A	POROSITY AT [C]

TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning [C] Center [E] End

	JOINT		CURRENT/VOLT			ELECTRODE	REINFORCEMENT		BACK BEAD		ROOT BEND	RADIOGRAPHY	
TEST NO.	R.O.	R.F.	ROOT	H.S.	BAL.	MFG./ DESIG.	HEIGHT	WIDTH	TOE	RESTART	PASS/FAIL	ACCEPT REJECT	REMARKS
10V2	3/32	1/16	100 24	140 28	110 26		1/32	1/4	GOOD	GOOD	P	A	—
10M2	3/32	1/16	100 24	145 27	105 26	AIRCO	1/16	3/8	GOOD	SLIGHTLY CONCAVE	NO TEST (SLIPPED IN JIG)	R	SLAG [B] - [C] AND NEAR [E]
1K3	3/32	1/16	75 24	98 27	80 26	VARIOS/ BH-100	3/32	1/4	EXCELLENT	GOOD. END OF WELD HAD CRATER PIT	P	R/E-C A/C-B	L.F-SCATTERED POROSITY [C] - [E] POROSITY [B] - [C]
1V3	3/32	1/16	85 22	100 24	90 23	VARIOS/ BH-100	1/16	1/4	UNDERCUT IN SOME AREAS	GOOD	NO TEST (FACE BENT)	A	POROSITY NEAR [C]
1M3	3/32	1/16	85 20	100 22	95 22	VARIOS/ BH-100	3/32	5/16	GOOD	EXCELLENT	P	A	SLAG NEAR [B]
3M3-P1	1/16	1/16	85	125	-	AIRCO	NO COMMENTS.						
3M3-P2	3/32	1/16	90	150	-	ATOM ARC	EXCESSIVE PENETRATION. RESTARTS NOT TIED IN PROPERLY.						
3M3-P3	1/16	1/16	90	150	-	ATOM ARC	PENETRATION AND RESTARTS GOOD.						
3K3	1/16	1/16	85 18	140 22	95 19		1/8	5/16	TWO AREAS OF VERY SHARP RE-ENTRY.	GOOD	F (2 CRACKS ≈1/8")	A	UNDERCUT NEAR [E] POROSITY NEAR [C]

TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning   [C] Center   [E] End

TEST NO.	JOINT R.O.	JOINT R.F.	CURRENT/VOLT ROOT	CURRENT/VOLT H.S.	CURRENT/VOLT BAL.	ELECTRODE MFG./DESIG.	REINFORCEMENT HEIGHT	REINFORCEMENT WIDTH	BACK BEAD TOE	BACK BEAD RESTART	ROOT BEND PASS/FAIL	RADIOGRAPHY ACCEPT/REJECT	RADIOGRAPHY REMARKS
3V3	1/16	1/16	90 18	170 26	100 20		1/16-3/32	5/16	MINOR UNDERCUT	GOOD	P	A	POROSITY NEAR [C]
3M3	1/16	1/16	90 20	140 24	105 22	ATOM ARC	1/8	1/4-5/16	GOOD	GOOD	P	A	SCATTERED SLAG [B] - [C] SCATTERED SLAG [C] - [E]
4K3	.045	1/8	135 21	200 25	140 22		1/16-1/8	1/4	SLIGHT AREA SHARP RE-ENTRY. ONE AREA LACK OF PENETRATION IRREGULAR WIDTH.	GOOD	P	A	——
4V3	3/32	1/8	95 20	130 24	120 22		1/16-3/32	1/4	GOOD MINOR POROSITY	GOOD	P	A	UNDERCUT [C] - [E]
4M3	1/16	1/16	85 20	115 22	140 26	ATOM ARC	1/8	3/8	INTERMITTENT MINOR UNDERCUT	GOOD	P	R	POROSITY CLUST. NEAR [C] POROSITY/SLAG NEAR [E]
5M3-P1	7/64	1/16	80	105	-	VARIOS/ BH	THE WELDING CURRENT WAS LOW. THE PENETRATION WAS GOOD BUT NOT UNIFORM. OUT OF FOUR RESTARTS, ONE FAILED TO TIE IN. THE BEAD APPEARED COLD.						
5M3-P2	7/64	1/16	84	125	-	VARIOS/ BH	THE SURFACE BEAD HAD A HIGH CROWN. THERE WAS SOME EVIDENCE OF POROSITY IN THE BACK BEAD.						
5M3-P3	3/32	1/16	86	130	-	VARIOS/ BH	SAME AS 5M3-P2. HOWEVER, BEAD SURFACE WAS GOOD.						

TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning [C] Center [E] End

	JOINT		CURRENT/VOLT			ELECTRODE	REINFORCEMENT		BACK BEAD		ROOT BEND	RADIOGRAPHY	
TEST NO.	R.O.	R.F.	ROOT	H.S.	BAL.	MFG./ DESIG.	HEIGHT	WIDTH	TOE	RESTART	PASS/FAIL	ACCEPT/ REJECT	REMARKS
5M3-P4	3/32	3/32	85	130	–	VARIOS/ BH	THE PENETRATION WAS INCONSISTENT. THE RESTART WAS NOT GOOD.						
5M3-P5	3/32	3/32	89	135	–	VARIOS/ BH	THE PROBLEMS WERE THE SAME AS 5M3-P4.						
5M3-P6	3/32	3/32	90	135	–	VARIOS/ BH	BLEW THROUGH CERAMIC.						
5M3-P7	1/16	3/32	90	135	–	VARIOS/ BH	INSUFFICIENT PENETRATION.						
5M3-P8	1/16	1/16	90	135	–	VARIOS/ BH	GOOD PENETRATION. RESTARTS WERE GOOD.						
5M3-P9	1/16	1/16	90	150	–	VARIOS/ BH	ELECTRODE "FINGERNAILED" FREQUENTLY. INCOMPLETE PENETRATION. (SEE NOTE 1)						
5M3-P10	1/16	1/16	85	140	–	VARIOS/ BH	ELECTRODE "FINGERNAILED" FREQUENTLY. WELDER HAS VERY LOW OPINION OF OPERATING CHARACTERISTICS OF THIS ELECTRODE. (SEE NOTE 1)						
5K3	3/32	3/32	95 22	122 28	95 22	VARIOS/ BH	5/32-1/8	3/16	GOOD	GOOD BUT WIDTH IS SMALLER.	P	A	—
5V3	3/32	1/16	95 24	120 28	100 26	VARIOS/ BH	1/16	1/4-5/16	UNDERCUT IN SOME AREAS	LOW BUT TIED-IN	P	A	PIPE POROSITY NEAR [B] OUT OF AREA OF INTEREST

TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning [C] Center [E] End

	JOINT		CURRENT/VOLT			ELECTRODE	REINFORCEMENT		BACK BEAD		ROOT BEND	RADIOGRAPHY	
TEST NO.	R.O.	R.F.	ROOT	H.S.	BAL.	MFG./ DESIG.	HEIGHT	WIDTH	TOE	RESTART	PASS/FAIL	ACCEPT REJECT	REMARKS
5M3	3/32	1/16	95 28	120 27	95 24	VARIOS/ BH	1/16-1/8	3/8-5/16	GOOD. BUT INCONSISTENT	GOOD	P	A	PIPE POROSITY NEAR [B] OUT OF AREA OF INTEREST (NOT REALLY)
7K3	1/16	1/16	90 18	135 22	105 20		1/16-1/8	3/16	ACCEPTABLE VERY IRR. IN REIN. AND WIDTH	POOR	P	A	UNDERCUT [B] - [C] POROSITY [C] - [E]
7V3	3/32	1/16	100 20	160 26	105 20		1/16-3/32	3/16-5/16	MINOR U.C. SOME AREAS (WIDTH SLIGHTLY INCONSISTENT)	GOOD	P	A	SLAG ABOVE [C]
7M3	3/32	3/32	100 20	160 24	105 22		3/32	1/4	MINOR U.C.	GOOD	P	A	UNDERCUT NEAR [B]
8K3	1/16	3/32	90 18	135 22	145 22		3/32-1/8	1/4	GOOD	GOOD	P	A	SCATTERED SLAG [B] - [C] SCATTERED SLAG [C] - [E]
8V3	1/16	1/8	90 20	180 26	130 22		1/16-3/32	5/16	SOME MINOR UNDERCUT	GOOD	P	A	UNDERCUT [C] - [E] U.C.,POR. [B] - [C]
8M3	1/16	1/8	95 22	210 26	140 24		1/16-3/32	1/4	GOOD	GOOD	P	A	POR. NEAR [E], U.C. SLAG SLAG NEAR [B]
10K3	1/16	1/16	85 20	145 24	100 22	AIRCO	3/32	1/4	FUSION LINE LOOKED COLD	SMALL CRATER PIT	P	A	PIPE POROSITY NEAR [E] OUT OF AREA OF INTEREST SLAG [B] - [C]

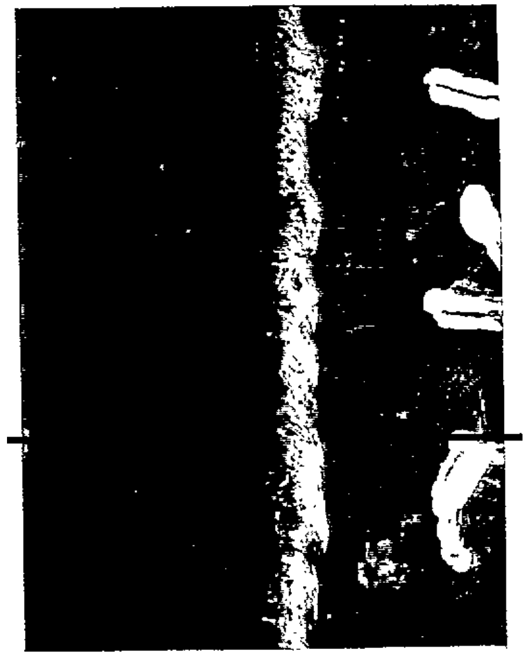
TABLE 4.1 (CONT'D)
PARAMETERS AND TESTING SUMMARY RESULTS

[B] Beginning [C] Center [E] End

	JOINT		CURRENT/VOLT			ELECTRODE	REINFORCEMENT		BACK BEAD		ROOT BEND	RADIOGRAPHY	
TEST NO.	R.O.	R.F.	ROOT	H.S.	BAL.	MFG./ DESIG.	HEIGHT	WIDTH	TOE	RESTART	PASS/FAIL	ACCEPT REJECT	REMARKS
10V3	3/32	1/16	95 22	130 25	95 22		1/32	5/16	UNDERCUT FOR 3" AT END OF RUN/ OTHERWISE - GOOD	GOOD	P	A	—
10M3	3/32	1/16	95 22	135 25	95 22	AIRCO	3/32	5/16-3/8	VERY SMOOTH	TIED-IN BUT LOW	F FRACT. FULL WIDTH. BRITTLE ZONE ABOUT TOP OF ROOT BEAD	A	POROSITY [B] - [C] POROSITY NEAR [E]

NOTE 1: THE VARIOS E7016 AND E7018 ELECTRODES USED WITH THIS EVALUATION PROGRAM EXHIBITED A PROBLEM IN THAT THE FLUX DID NOT MELT OFF CONSISTENTLY WITH THE WIRE CORE. THIS CONDITION CREATED DIFFICULTY IN ESTABLISHING PROPER ARC LENGTH AND RESULTED IN LACK OF FUSION, SPATTER AND POROSITY. THIS "FINGERNAILING" WAS MOST TROUBLESOME IN THE HORIZONTAL (2G) POSITION. IN THE FLAT (1G) AND VERTICAL (3G) POSITIONS, MORE MANIPULATION ROOM WAS AVAILABLE TO FACILITATE "FINGERNAIL" BREAKAGE AND RESULTANT ARC LENGTH SHORTENING.

FIGURE 4.1
(Index To Figure 4.1)



3K1

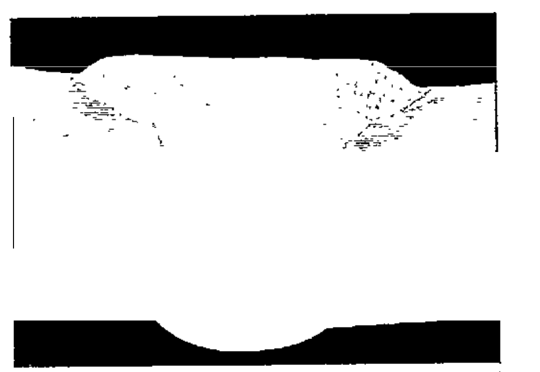


FIGURE 4.1
E.7016, 1/8" FLAT

REPRESENTATIVE BACK BEAD CONFIGURATIONS AND CROSS-SECTIONAL MACROPHoTOGRAPHY

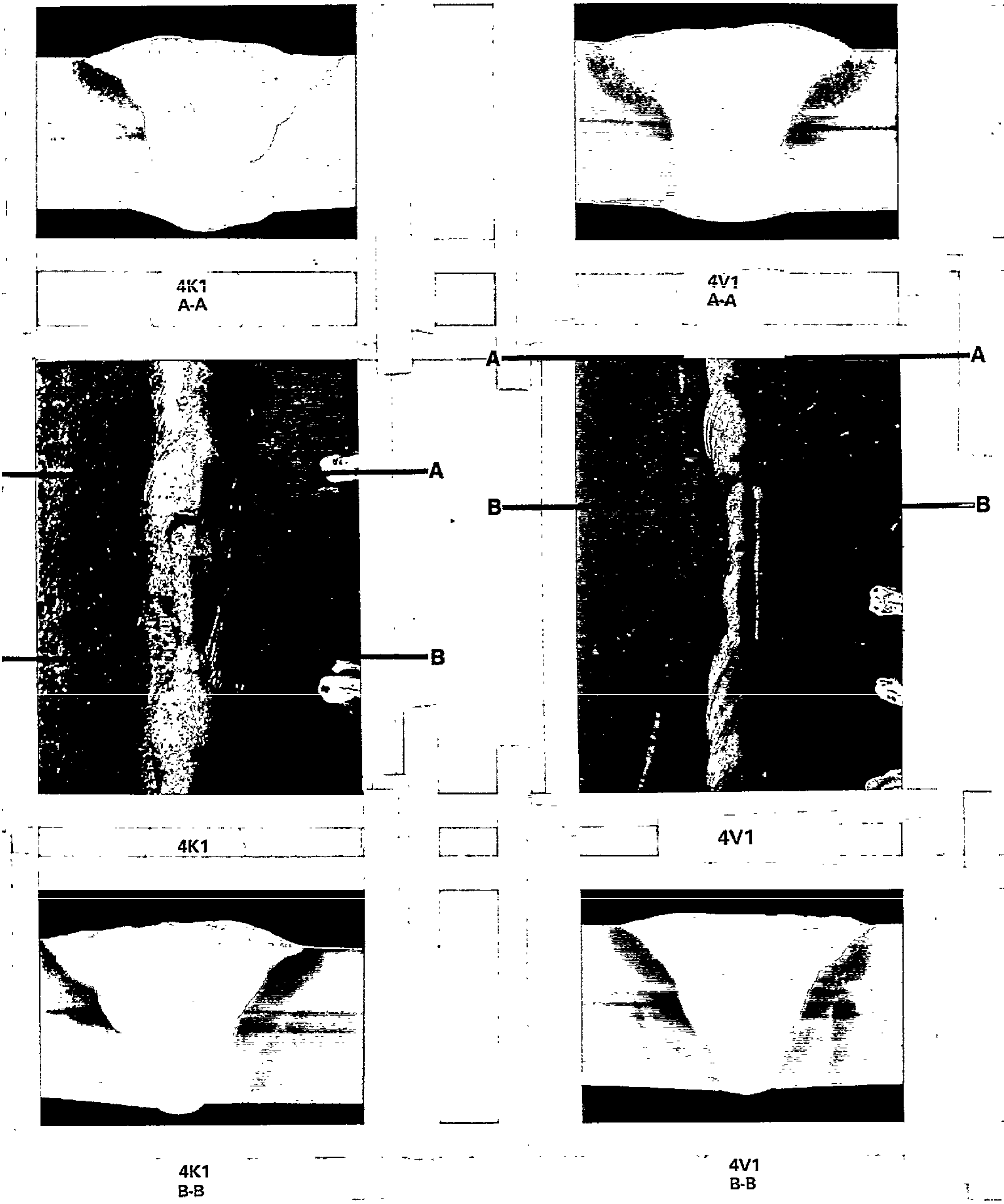
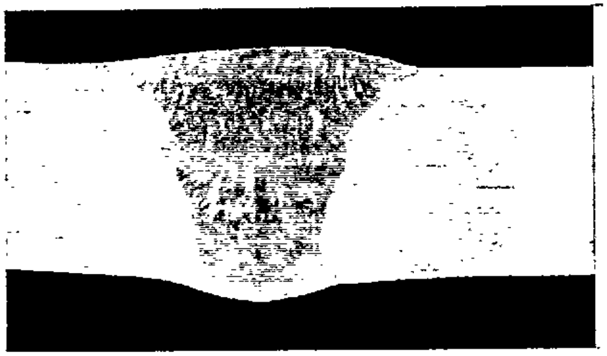
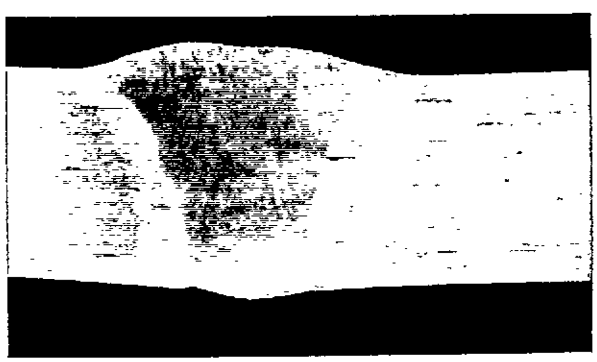


FIGURE 4.1 (Continued)
E-7016, 5/32" FLAT



5K1
A-A

5K1



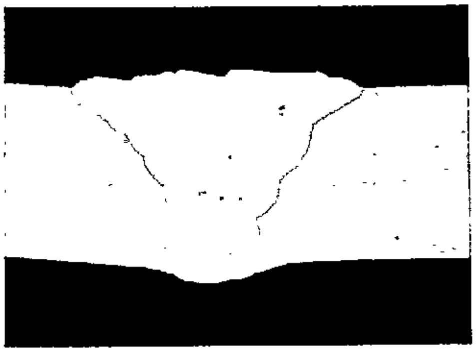
5K1
B-B

FIGURE 4.1 (Continued)
E-7018, 1/8" FLAT

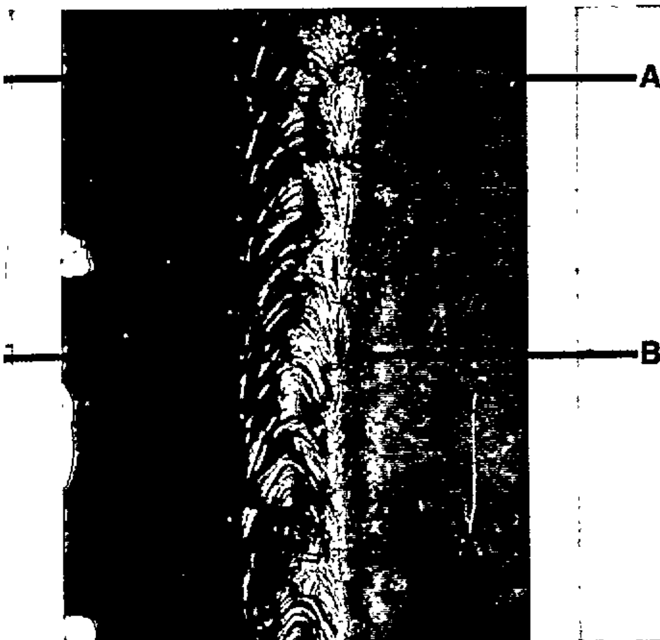
7V1

7 K 1

FIGURE 4.1 (Continued)
E7018, 1/8" FLAT

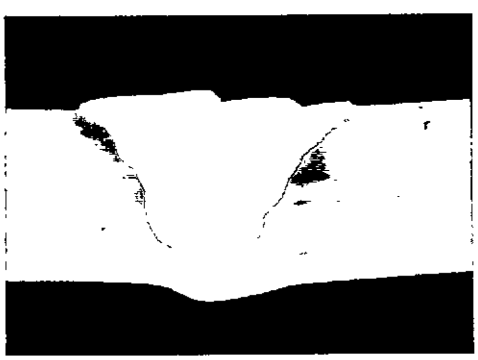


10K1
A-A



10K1

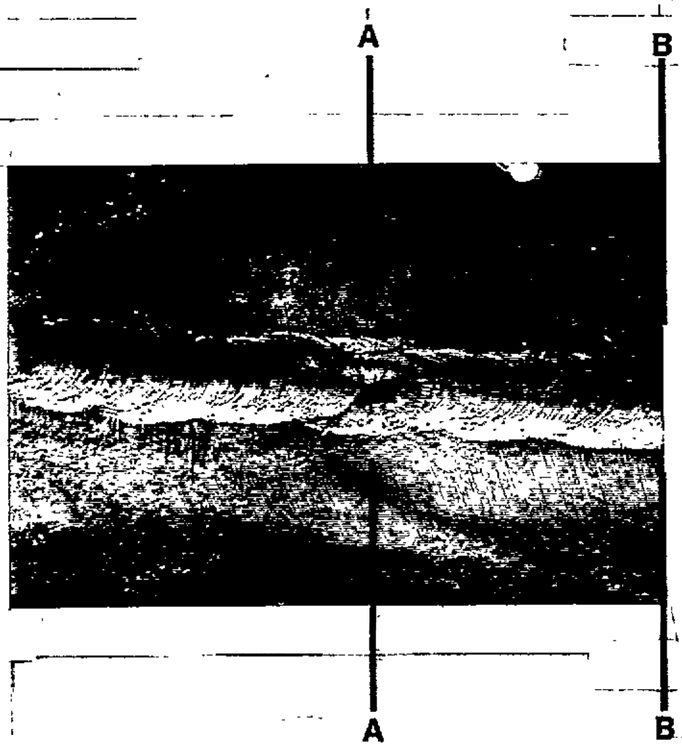
10M1



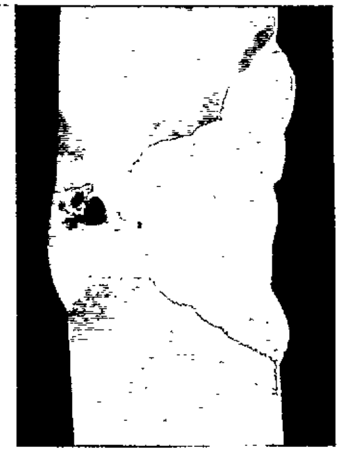
10K1
B-B

FIGURE 4.1 (Continued)
E-6010, 1/8" FLAT

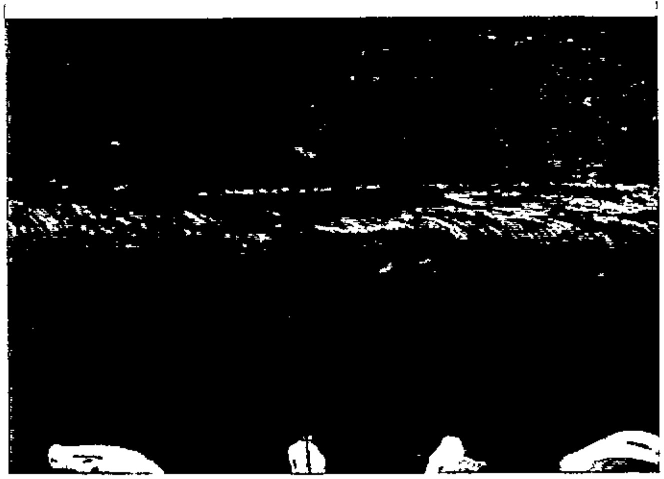
3M2
A-A



3M2



3M2
B-B



3V2

FIGURE 4.1 (Continued)
E-7016, 1/8" HORIZONTAL

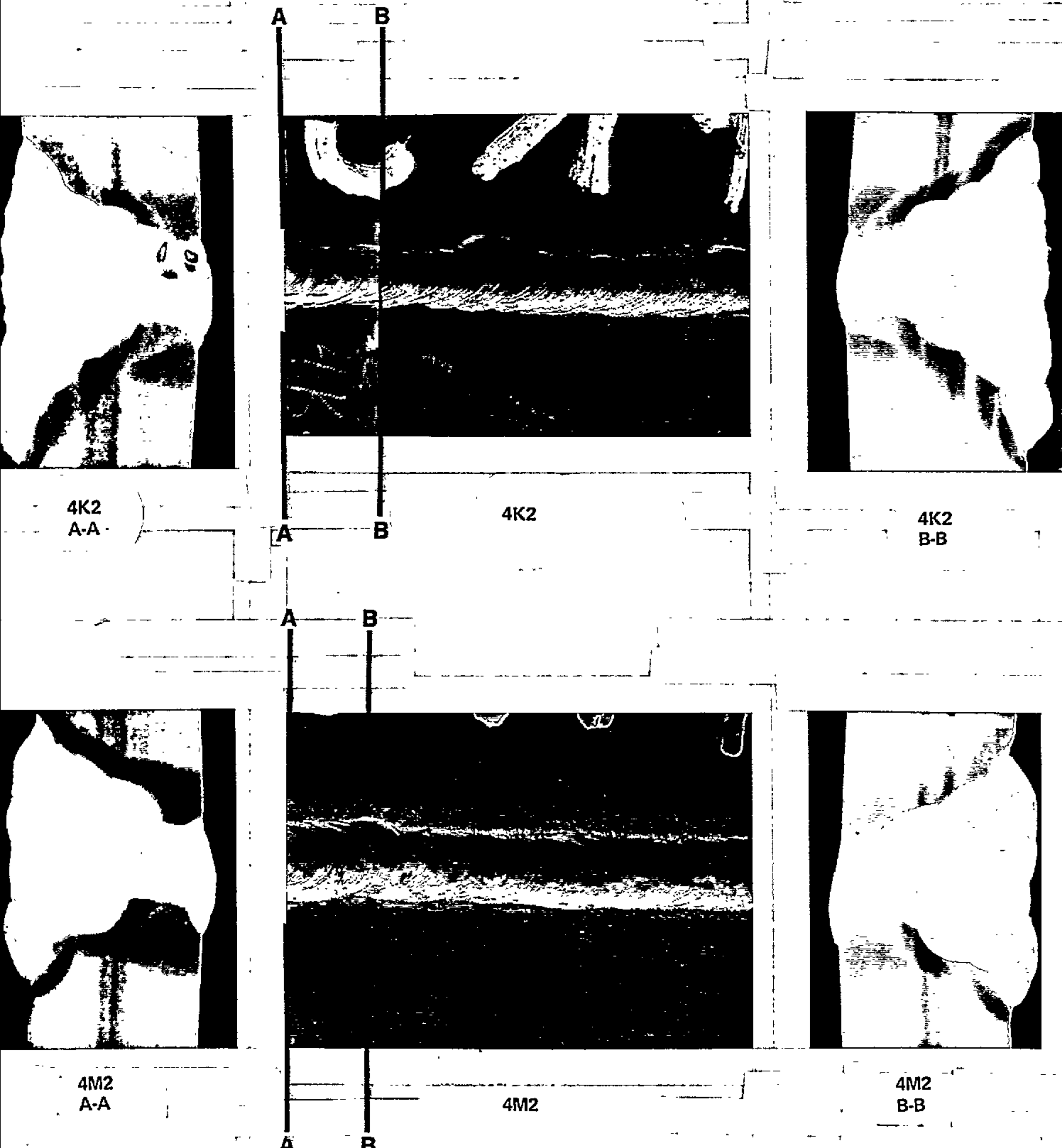
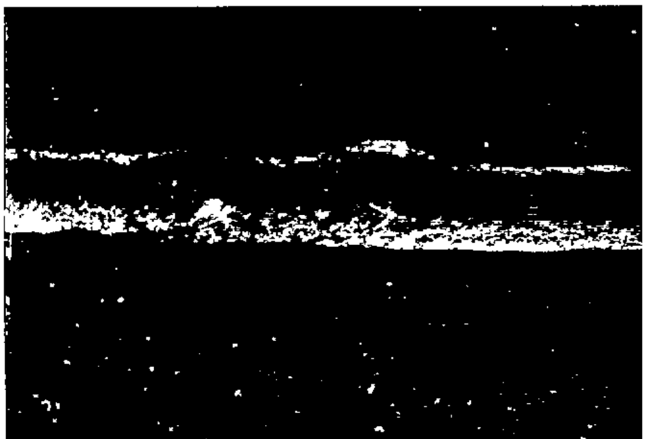


FIGURE 4.1 (Continued)
E-7016, 5/32" HORIZONTAL



7V2

7M2

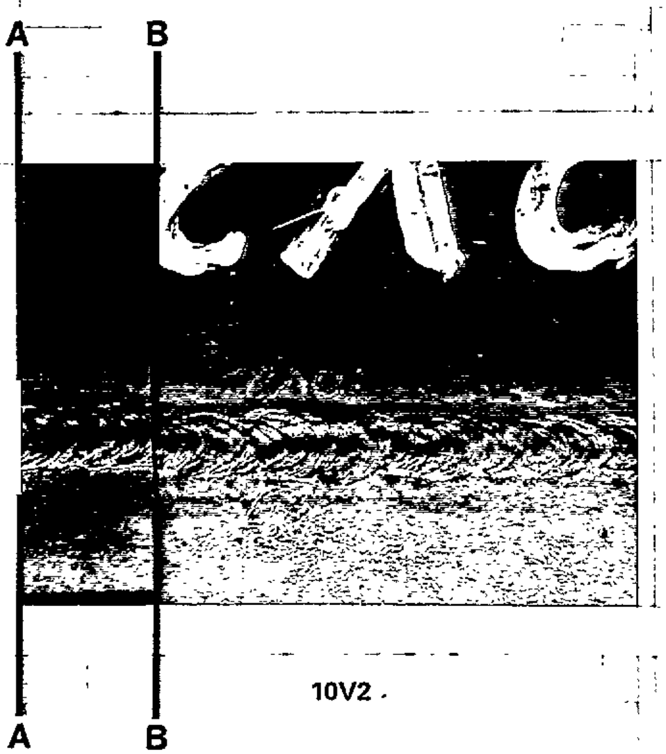
7K2
A-A

7K2

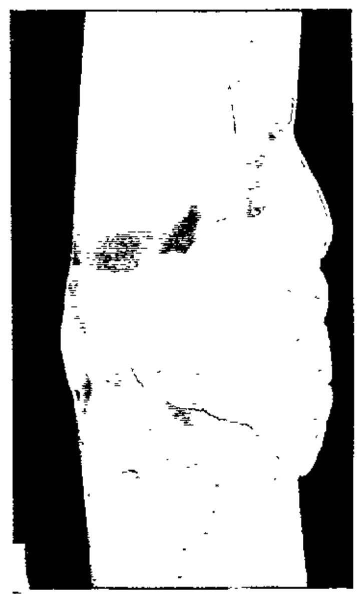
7K2
B-B

FIGURE 4.1 (Continued)
E-7018, 1/8" HORIZONTAL

10V2
A-A



10V2

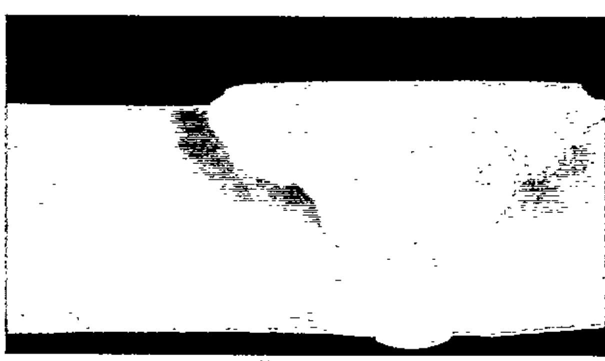


10V2
B-B

FIGURE 4.1 (Continued)
E-6010, 1/8" HORIZONTAL

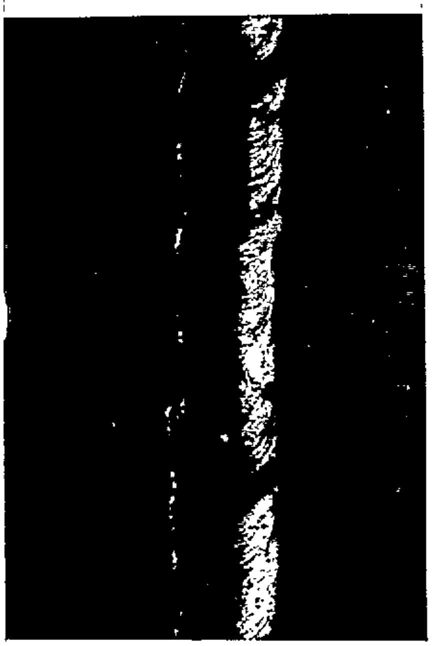
4K3
A-A

4K3



4K3
B-B

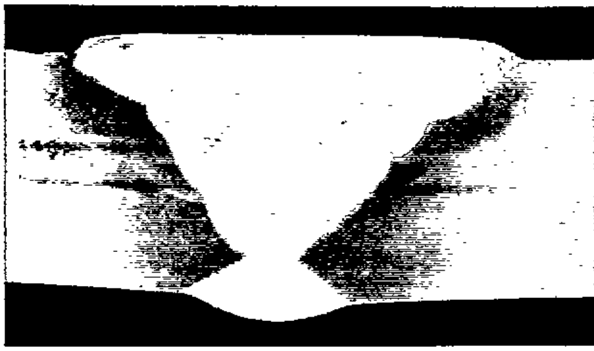
FIGURE 4.1 (Continued)
E-7016, 5/32" VERTICAL



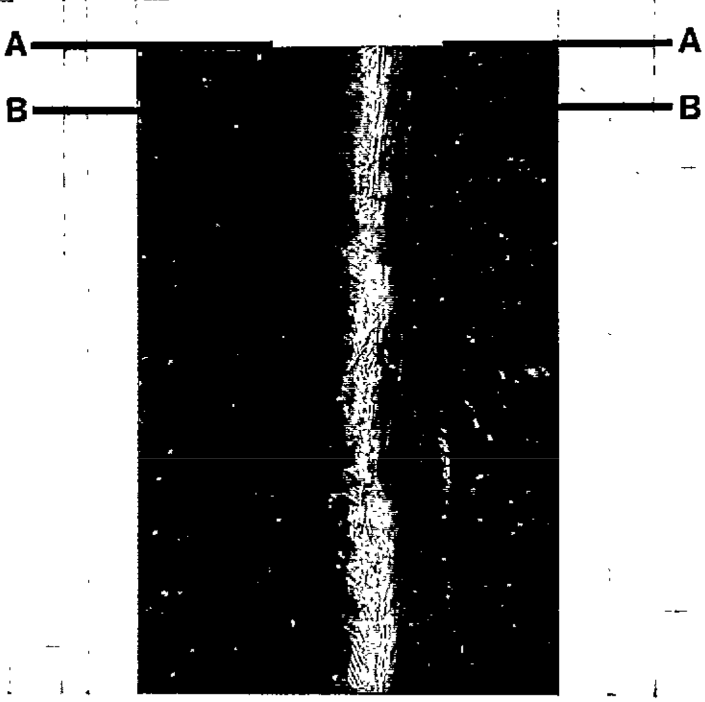
5V3

7M3

FIGURE 4.1 (Continued)
E-7018, 1/8" VERTICAL



8M3
A-A



8M3

8M3
B-B

FIGURE 4.1 (Continued)
E-7018, 5/32" VERTICAL

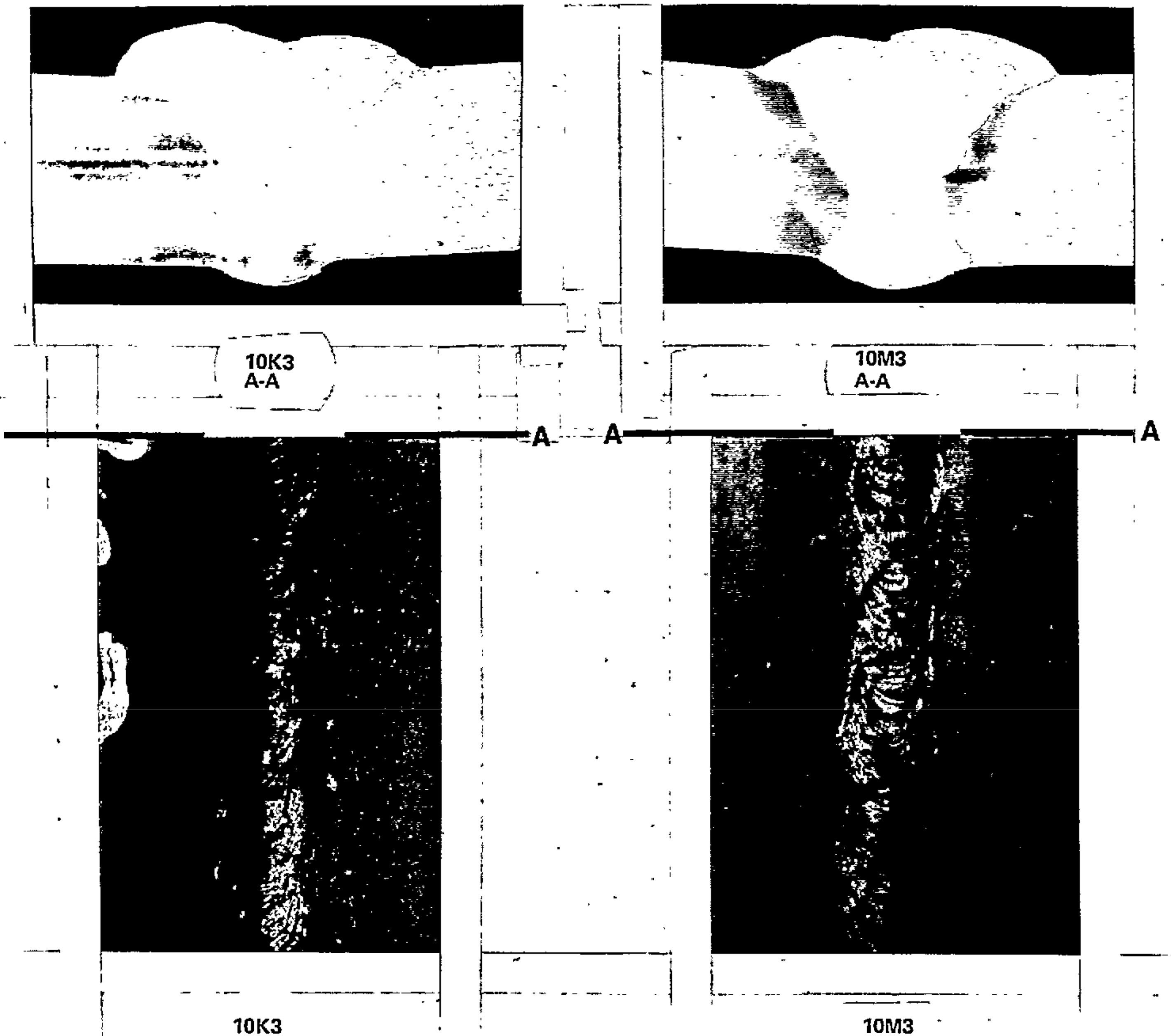
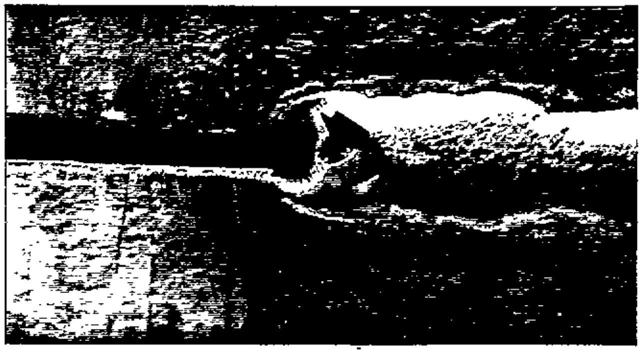


FIGURE 4.1 (Continued)
E-6010, 1/8" VERTICAL



A

BACK BEAD STOP AREA SHOWING SLAG POCKET & "KEYHOLE"

B

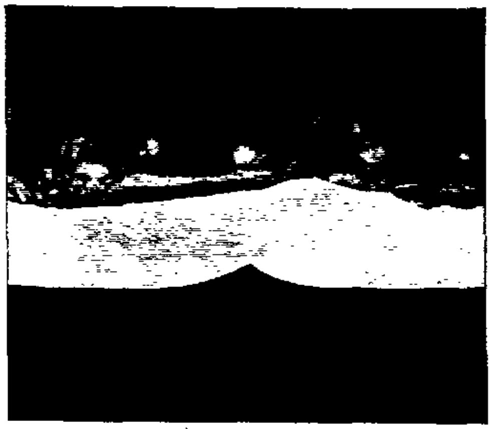
LONGITUDINAL SECTION SHOWING UNDER-BEAD CRATER SLAG INCLUSION

C

LONGITUDINAL SECTION SHOWING COLD START WHICH FAILED TO REMOVE UNDER-BEAD CRATER SLAG INCLUSION

FIGURE 4.2
E7018, 5/32", FLAT

LONGITUDINAL MACROPHOTOGRAPHS OF STOP AND RESTART AREAS



D

LONGITUDINAL SECTION OF COLD START OVER STOP

E

LONGITUDINAL SECTION OF HOT START OVER STOP

FIGURE 4.2 (CONTINUED)

5.0 ANALYSIS

5.1 Back Bead Contours

The use of ceramic tile backing with low hydrogen, one-side SMAW normally resulted in satisfactory back bead contours as determined by height - width of reinforcement, reentrant angle consistency and general satisfactory back bead contours also resulted with E601O electrodes. The satisfactory back bead contours obtained in both non-restart and restart areas with low hydrogen one-side SMAW over ceramic tile backing were found to be primarily -dependent on welding technique. Ceramic type was found to have an insignificant effect on back bead contour while variations due to electrode type and welding parameters were not significantly different than those normally encountered without ceramic tile backing.

5.1.1 Back Bead Contours for Non-Restart Areas

The back bead contours for non-restart areas were generally satisfactory. The principle difficulty was failure to achieve adequate penetration, a technique-related problem indirectly related to ceramic tile backing.

With conventional fulll penetration, open root, one-side SMAW, the welding technique margin for error is extremely narrow. The welder must strive for adequate penetration via use of the keyhole technique. However once a keyhole is formed, care must be exercised to avoid burn-through or puddle breakdown in which case the force of the arc or gravity overcomes the Puddle's capillary support. For the larger low hydrogen puddle, the “window” of acceptable technique between inadequate penetration and burn-through is quite narrow and changes of course with Variations in joint geometry obtaining a keyhole is primarily a function of travel speed. A travel speed too fast will not melt the root faces ahead of the puddle due to inadequate time. Alternatively, a travel speed too slow permits cooler liquid metal to run into the groove ahead of the puddle. This metal bridges the root opening rather than melting the root faces. Additional metal. added as the arc passes, lies atop the bridging metal. The bridging metal shields the root faces from melting and the result again is inadequate penetration and a narrow back bead, as shown in photomacrographs 4K3 and 4Vl of Figure 4.1. The appropriate travel speed for a given electrode and Parameters will vary somewhat with dimensions of the root faces, root opening and joint mismatch.

In conventional open root, one-side SMAW, if a keyhole is established and the puddle becomes too large, the puddle can no longer be held in place by capillarity with the joint edges and uncontrolled flow occurs. The force of the arc may push away the molten puddle through opening and "burn-through" occurs. This has tendency to occur frequently with - hydrogen electrodes due to the large puddle and occasionally with E601O. Since very fine touch is required with low hydrogen electrodes to avoid burn-through on one hand and inadequate penetration on the other, low hydrogen, open root welding is usually Shunned if an acceptable alternative exists. With ceramic tile backing, burn-through is avoided because the ceramic holds the larger puddle in position for the critical Solidification time. An experienced welder, however, who remembers previous had results with low hydrogen, oepn root welding, must develop a confidence factor when utilizing ceramic tile backing. Fran prior open root experience, the welder's first tendency is to travel too fast with inadequate penetration frequently resulting.

As mentioned, variations- in joint geometry comlicate the conventional open root welding operation by necessitating changes in welding technique as the bead progresses. Since the margins for error of welding techniques are quite narrow, a very high level of skill and judgment are required to make appropriate- compensation for changing joint geometries. Joint variations may occur due to poor initial fitup and/or narrowing of the root opening ahead of the puddle as the puddle solidifies and contracts. Shrinkage of the root opening due to contracting weld metal is controlled in certain commercial operations by wedging the root opening at appropriate intervals. The wedges are removed as the bead approaches them. However fitup variations do occur and some intermedi'ate contraction ma y occur between wedges. Ceramic tile backing, by providiq additional puddle support, makes the one side SMAW process, especially with low hydrogen electrodes, significantly more forgiving. However unless the welder develops sufficient confidence in ceramic tile backing he may "ride" the puddle fearing burn-through if he "key-holes" . He might thus choose to use hot Start overcome the resulting lack of penetration. Since other than_ intermittent use of hot start would overheat the electrode coating, this is definitely not to be preferred to the keyholing technique. Intermittent hot start might be justified was was used in this evaluation for extreme variations in joint fitup, although a double welded joint might be considered in such cases. Intermittent use of hot start usually leads to extreme variation in back bead width.

As mentioned, it was found advantageous to on occassion use the continuously variable feature of the OPS hot start (i.e. , from normal root current to full start current) for areas other than restart areas. This was sometimes Utilized on normal run areas where the root opening began to close due to weld solidification contraction, where irregular fitup resulted in tight root openings or in instances of irregular-ly thick root faces. Such areas would normally begin to result in lack of penetration if appropriate technique Changes are not initiated. The welder can obtain extra current to the degree necessary up to full hot start current to melt through such areas and maintain full penetration. On photomacrograph 4K3 of Figure 4.1, it appears the back bead was narrowing as welding progressed. The welder assessed the condition and turned the hot start on to again achieve full penetration, taking advantage of the ceramic backing to support the puddle. On the actual plate (including a portion not in photograph) it appears this happened twice becoming narrower the first time while moving off the run-off tab. Generally, when the root opening began to close, the welder either terminated t he weld or activated the hot start.

variations in back bead contour with respect to electrode type were observed between the low hydrogen electrodes and organic coated electrodes. Variations between the E7018 low hydrogen iron powder and the E7016 low hydrogen without iron powder were insignificant. The organic coated E601O elec- trode, a fast-freeze electrode producing a small puddle, predictably resulted in noticably different back bead contours than those achieved with the low hydrogen elec trodes. There was much less continual effect due to ceramic tile backing for the E601O electrode, the electrodes seldom in fact actually melted the ceramic tiles. Flat areas observed on the back bead, as shown in photomacrographs 10KL and 10ML (Fig. 4.1), evidenced, however, an occasional needd for puddle support. The E601O back bead surfaces were considerably rougher than the surfaces resulting with low hydrogen electrodes.

5.1.2 Back Bead contours for Restart Areas

The back bead contour for restart areas was generally satisfactory when utilizing hot starting. Many restart areasho were almost indistinguishable from the remainder of the bead. The back bead contour for restart areas was dictated primarily by restart technique and secondarily by stopping technique. Principal defects observed were low areas or "gaps" in reinforcement continuity and conversely locally excessive reinforcement or "bumps". An additional problem was failure to establish a keyhole at the restart, resulting in a narrow back bead beginning at the restart area. This was sometimes corrected by the use of hot start short distance from the restart area once the condition was identified. The necessity for coordination of electrode travel with the hot start cycle is evidenced in 4Kl of Fig. 4.1. Optimum penetration in this instance was not obtained in the restart area. The bead began to penetrate but travel speed was excessive and the hot start terminated prematurely. Penetration decreased and the back bead narrowed. The welder then reinitiated the hot start and regained full penetration. In another instance, 4V1 (fig. 4.1) typifies a very narrow restart area where the crater of the previous stop was not melted through. Upon restarting, the welder apparently failed to realize the condition and terminated the hot start prior to moving off the stop crater from the previous bead. A keyhole wasn't forming so the welder reinitiated the hot Start to regain penetration. The series of events in 4Vl and 4KL were similar except that in 4VL, slightly less penetration was obtained.In both instances, the welder terminated the hot start prematurely, realized wasn't obtaining adequate penetration, then reinitiated the hot start as a corrective measure.

5Kl (Fig 4.1), in the wide back bead area, typifies a good restart obtained with proper hot-start technique. 4K3 provides an example of an area where ceramic melt occurred at the restart and did not occur on the prior bead.

5.2 Weld Soundness

The cold starting technique conversely, was found to simply not possess the "arc drive" necessary to achieve full penetration at restart areas (See 4.2 C & D). As a result, the employment of cold starting without complete crater taper-grinding is not recommended.

The use of ceramic tile backing with low hydrogen and with E601O electrodes normally resulted in satisfactory weld metal soundness. Weld metal soundness was determined by radiographic examination of each regular test assembly, by root bend testing of each regular test assembly from a location randomly selected along the approximate 8" length of weld, and by cross-sectional macrophotography of selected areas of representative test assemblies. Several additional stop and restart tests were performed. Relatively few traditional-defects such as slag, porosity, uudercut, and lack of fusion were detected. The resultant weld defect rate is considered to be comparable to that experienced in a similar environment without ceramic backing.

Two defect categories potentially attributable to ceramic tile backing however, were identified. The first was a chevron porosity and piping problem similar to that encountered previously with FCAW over ceramic backing. The second was slag inclusions at stop and restart areas, the frequency of which was quite dependent on welding technique.

5.2.1 Weld soundness for Non-Restart Areas

Chevron porosity and piping did not occur as frequently with SMAW as it did with FCAW (Ref. 1). The option of placing the arc at the center or at the leading edge of the puddle to achieve a satisfactory back bead contour however, does not exist with SMAW as it did with FCAW. The leading edge of the SMAW puddle is not hot enough to melt the root faces and thereby obtain full penetration unless the SMAW arc is directly over it.

Disregarding the beginning and end effects of the run-off tabs (usually piping existed there), Chevron porosity and/or piping (as distinguished from other porosity) existed in one flat position plate (3M1-P3), seven horizontal position plates (3M2, 4M2-P1, 4M2-P2, 4M2-P3, 4M2-P4, 4K2, 7K2) and in no vertical position plates. The absence of Chevron porosity and piping in vertical positio n SMAW plates is consistent with FCAW results. Apparently the vertical welds with SMAW, as with FCAW, vent any disolved gases upward and out of the puddle relatively unrestricted. As shown in photomacrographs 3M2 and 4K2 of Figure 4.1, the chevron porosity and piping which occurred in the horizontal position plates was always in the upper half of the weld section, adding further support to the theory that dissolved gases rise and become trapped upon weld metal solidification. No other soundness problems were identified in non-restart areas. Test assembly 10M3 root bend fractured due to a brittle zone which appeared to be in the second pass. It does not appear related to ceramic backing.

5.2.2 Weld Soundness for Restart Areas

In restart areas, chevron porosity was found to be nonexistent. Non-chevron (traditional) porosity warranting rejection to the radiography requirements of ABS and/or NAVSHIPS occurred only in plates IK3 and 4M3. It is assumed that this occurrence rate is well.within the realm of normal frequency and is not attributable to ceramic backing.

Restart areas were otherwise generally sound but were occasionally plagued by slag inclusions or pockets apparently inherent to low hydrogen electrodes over ceramic backing. An interesting disclosure from the further investigation identified in 3.2 was the formation of a slag pocket under the end of some stop craters. This phenomenon, having the appearance of liquid slag rolled beneath the weld puddle and entrapped prior to puddle solidification is depicted in Fig. 4.2B. The crater slag pockets were found to exist inherently open to the root bead back side and are assumed to be attached to the ceramic "under-slag" upon solidification. It further suggested from this evaluation and from investigation by others(ref. 2), that the under-bead crater slag phenomenon is potentially a common occurrence with low hydrogen SMAW over Ceramic backing regardless of the stopping techniques employed.

Although their presence is assumed likely in low hydrogen **SMAW** ceramic backing applications, tier-bead crater slag inclusions by virtue of location cannot be detected from the working side. The awareness, however, of their liklihood was found beneficial in rectifying the inclusion phenomenon through employment of the hot start re-**starting** technique. With hot start, the necessary heat is available to remelt weld metal encompassing the entrapped slag, to remelt the entrapped slag (or at least the "neck" to detach it), and to provide the slag Sufficient time to float out of the puddle prior to re-solidification. A conventional cold start technique, as indicated in the longitudinal section results (see Fig. 4.2C), does not begin to accomplish this necessary criteria. Cold start remelting, as suggested by numerous macrophotos, would normally penetrate only the top periphery of the slag pocket.

The cold start technique used in conjunction with complete crater taper-grinding although not a major scope consideration in this evaluation, would have possible merit in certain production applications. It is opinions that such a combination would perhaps decrease the occurrence of crater slag inclusions in completed welds, but at the same time have a quite negative impact on cost effectiveness.

Within the stop of this investigation, slag inclusions were identified by radiography on plates lMl, 1OM2, lM3, 3M3, 4M3, 7V3, 8K3, 8M3 and 10K3. The only plates in which it was severe enough to warrantnt rejection to ABS and/or NAVSHIPS were 10M2 and 4M3. Since 10M2 was welded with an E601O electrode in which the ceramic backing had no significant effect in forming the weld bead, that slag is probably unrelated to ceramic tile backing. The rejectable slag inclusion in plate 4M3 might be related to ceramic backing. One rejectable slag inclusion with low hydrogen electrode over ceramic backing out of fifty-four such plates is witin an acceptable frequency range. It must be remembered however, that these statistics are derived from resultant data in Which the majority of terminal craters were neither conventionally filled nor taper-ground. In production applications, as previously stated, conventional filling techniques may be required as a means of controlling crater cracking. With the fuller conventional crater of less inherent taper, taper-grinding prior to hot starting may be required as necessary to effectively minimize the occurance of entrapped root crater slag.

6.0 SIGNIFICANT CONCLUSION_ AND RECOMMENDATIONS

Ceramic tile backing in conjunction with was found to be beneficial with both low hydrogen and organic type electrodes. For low hydrogen open root welding (for situations where this combination is essential) ceramic tile backing essential makes this process possible. By providing puddle support for the large, fluid low hydrogen puddles ceramic tile backing brought a process normally used only by the extremely skilled welder into the realm of capability of the average welder. For organic type coatings in open root welding applications, the use of ceramic tile backing appeared to greatly reduce the reject rate. Although puddle support is not required with organic coated electrodes to the degree it is with low hydrogen electrodes, ceramic tile backing, by providing that puddle support at the intermittent tires it is needed, reduces the historic defect rate obtained with organic coated electrodes.

The two significant problems occurring with ceramic tile backing, chevron porosity and piping and slag inclusions at step/restart areas, were found necessary to address. chevron porosity and piping Occurred most frequently in the horizontal position. It did not occur as frequently as it did with FCAW. The slag pockets at stop and restart areas usually occurred with the heavy slagging, low hydrogen electrodes and appears inherently related to the slag from the melted ceramic tile. Stopping and restart techniques Which provide sufficient penetration to melt around the slag pocket and the pocket itself together with enough time to float out the melted slag are essential. Such stopping and restart techniques exist and are operationally Possible. Hot start is an essential part of the necessary restart techniques. Hot start could also be used intermittently for bead shape purposes rather than removal of slag pockets, however appropriate welding techniques made possible by ceramic tile backing should render-this unnecessary in anything but extreme cases.

Ceramic tile backing is recommended on the basis of these evaluation results for all low hydrogen, open root welding and for critical applications involving organic coated electrodes with open root joints. Hot start and appropriate manipulation techniques are usually necessary to prevent slag inclusions at stop and restart areas. Awareness of the possibility of chevron porosity and piping, especially in the horizontal position, must be addressed. Stringent Welder training to develop a confidence factor to utilize "Keyhole" techniques not previously possible without ceramic tile backing should, as a rule, eliminate the need to employ hot start in other than start areas, but hot start could be used as necessary to obtain appropriate bead shape.

7.0 REFERENCES

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2. Blamquist, P.A.; July 1981; "Hot Start - The Key to Successful SMA Welding With Ceramic Backing"; Welding Journal.